Scenario Affordability Analysis

Review of Human Space Flight Plans Committee

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Costing Lead: The Aerospace Corporation

assisted by NASA staff from HQ, JSC, SSC, MSFC, and KSC

August 12, 2009

Timeline and Process to Today

- 7 potential HSF scenarios briefed by Dr. Crawley on August 5th, ~160 hours ago
- Committee members finalized the most ground rules and assumptions for the costing exercise by late Friday
- From last Thursday through (very) late last night, Aerospace ran costing model for the scenarios and derivatives, (based on different launch vehicles and assumed funding levels)
- Multiple telecons and other discussions (often lasting more than 3 hrs) were held daily with the Committee members, Aerospace and the NASA team to review multiple iterations of the costing output, validate the data, and resolve any issues

Timeline and Process to Today

- Today's product is significantly better than when we started 160 hours ago….

Key Ground Rules and Assumptions

- Aerospace used a 1.51 historical risk factor on all element development costs of all scenarios on the cost to go. A lower (1.25) historical risk factor was used on production/operations

- An additional $200 million was added to the COTS cargo baseline in FY 2011 to incentivize current COTS cargo demonstrations

- Except for international partner agreements already assumed for the ISS, all elements were fully costed (for costing purposes only)

- For all scenarios, except the Program of Record, assume a technology program starting at $500M in FY 2011 and ramping up to $1.5 billion over five years. Maintain the $1.5 billion annually thereafter. (Assume double counting in other ISS and EMSD lines, so funding line is one-half of that).

Key Ground Rules and Assumptions

- For scenarios that assume commercial crew, assume a $2.5B NASA investment over 4 years beginning in FY 2011
- Use Aerospace contract termination/restart model and actual contract termination costs in Cx programs
- For all scenarios that include refueling, assume technology line funds development and add a $1 B one-time cost to flight certify the fuel transfer kit
- For scenarios assuming lunar sorties/outpost, use the Cx estimate for the Altair lander and lunar surface systems; for the Deep Space options, assume a commercial lunar lander, but a government furnished ascent stage.

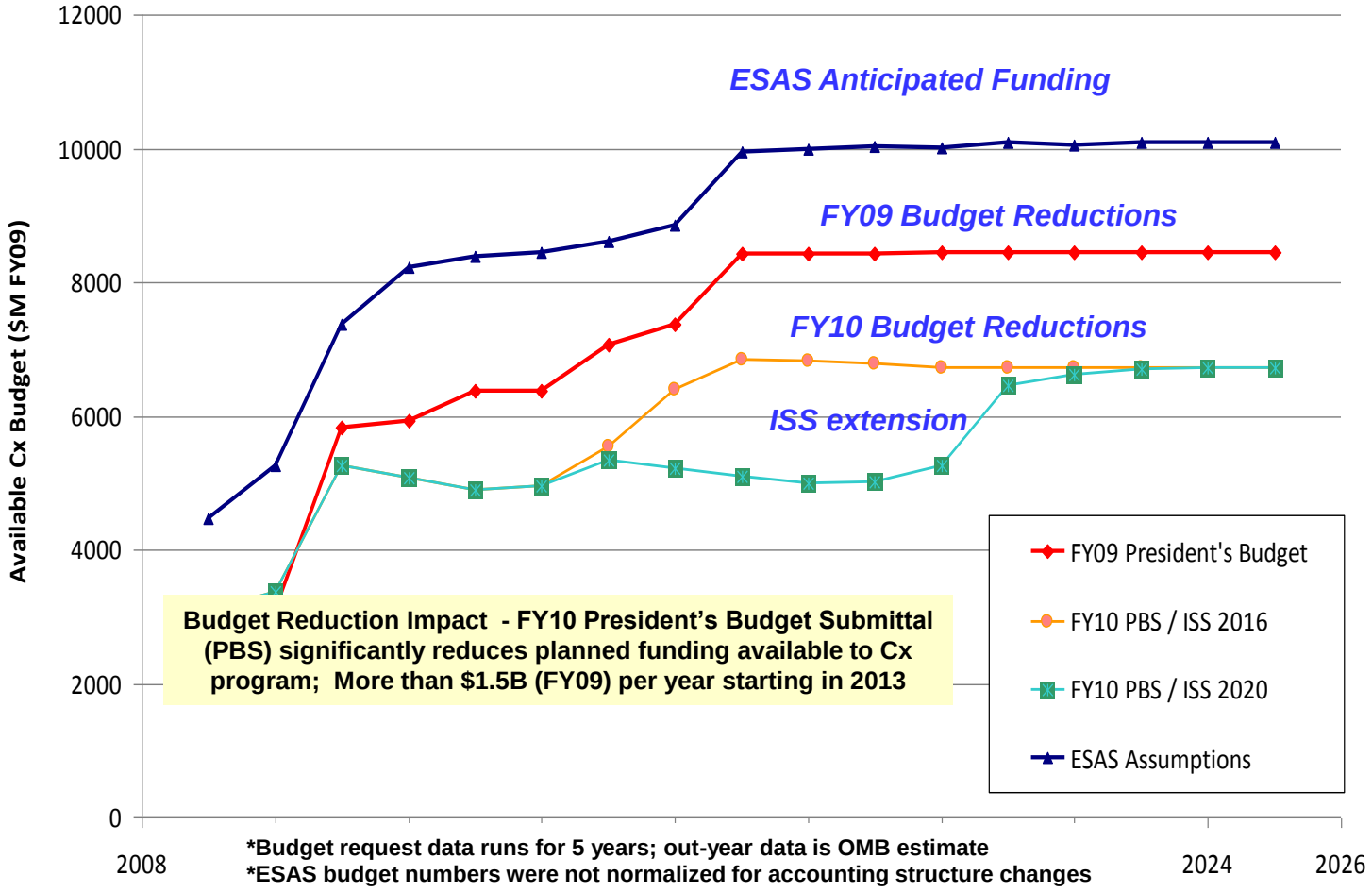
Key Ground Rules and Assumptions

- For options using EELV heavy lift launch vehicles, cost as if NASA does not build the system and uses NASA infrastructure and workforce only when required to conduct operations

- For the Shuttle Derived Systems scenario, assume Side-mount costs (provided by NASA) for the cargo only version

- Current program elements (ISS & STS):
  - For scenarios with ISS de-orbit in 2016, assume additional $1.5 B cost beyond current estimate
  - For scenarios with existing shuttle manifest, assume fly-out to March, 2011

Projected Constellation Program Funding has seen Significant Reductions since ESAS



Methodology for all Scenarios

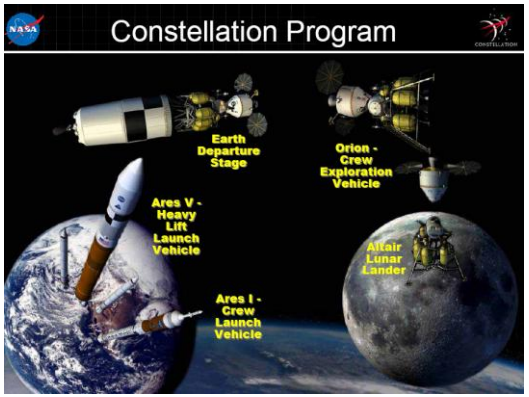
- **Step 1:** Build up budget charts for a particular scenario (not constrained to budget)

- **Step 2**: Fit scenario costs to given budget (e.g., FY10), adjusting schedule (deterministic)
  - Allocate funding & reserves to projects to raise total program cost to 65% likelihood
  - (Assume no cost penalty for re-planning budget)

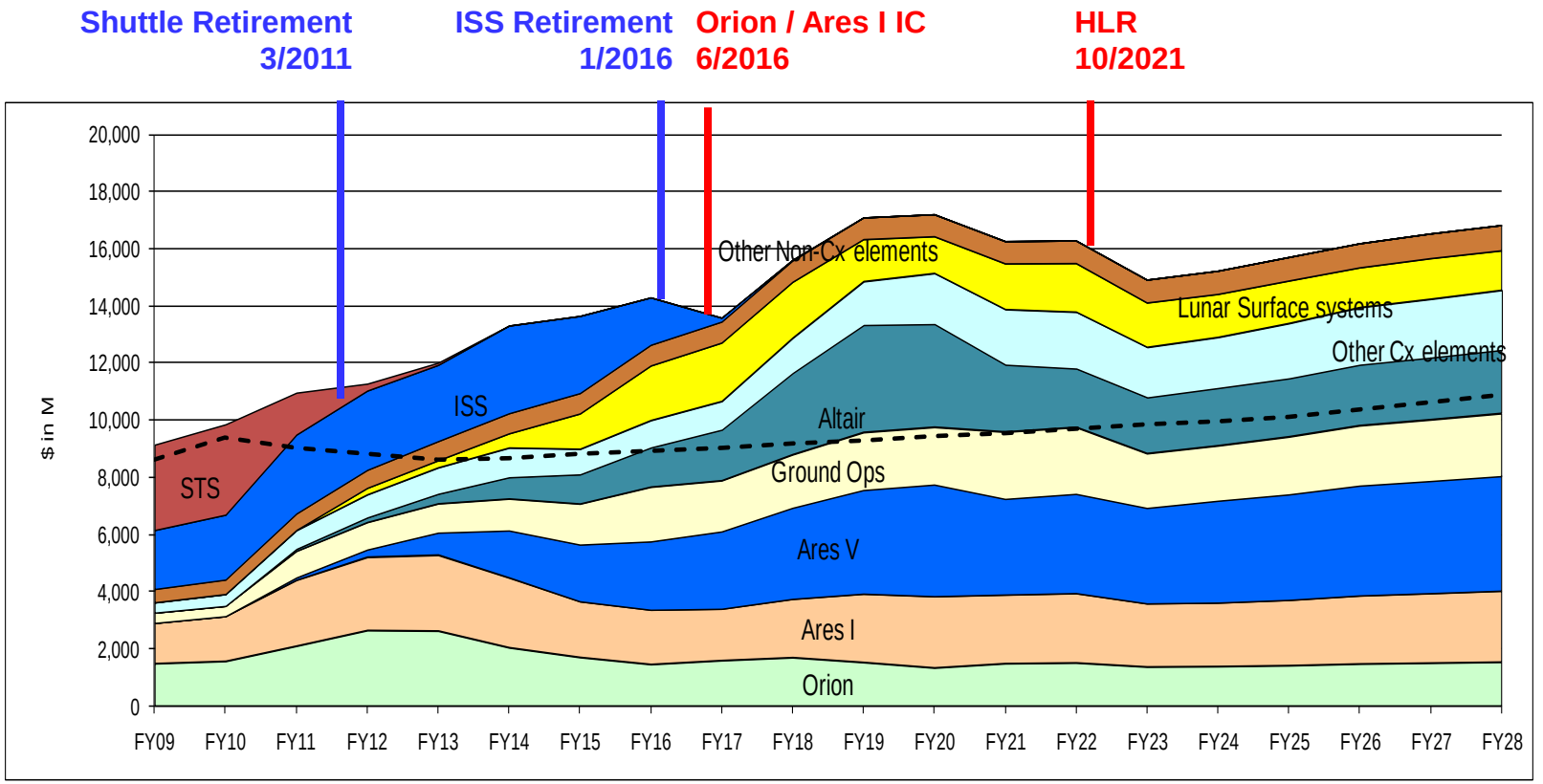
- **Step 3**: Assess impact of technical/historical risk on execution of scenario (probabilistic)
  - Monte Carlo analysis to simulate cost growth on elements, interactions of projects in constrained budget, etc.
  - Cost penalties are incurred for stretching out development to fit budget

Program of Record

- Existing Constellation program and budget
- Shuttle fly-out in March, 2011
- ISS retirement in early 2016
- Commercial/International Engagement as in program



Program of Record Derived Baseline - Unconstrained

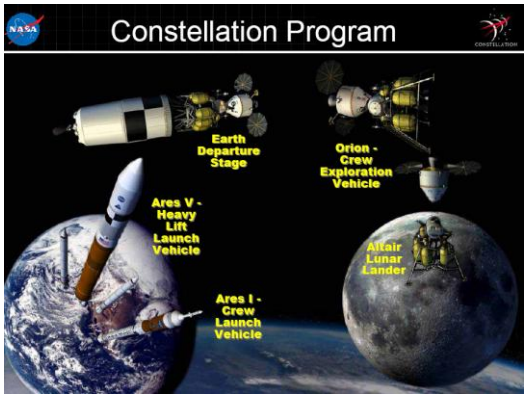


Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2016
Extra Soyuz flights for crew to ISS

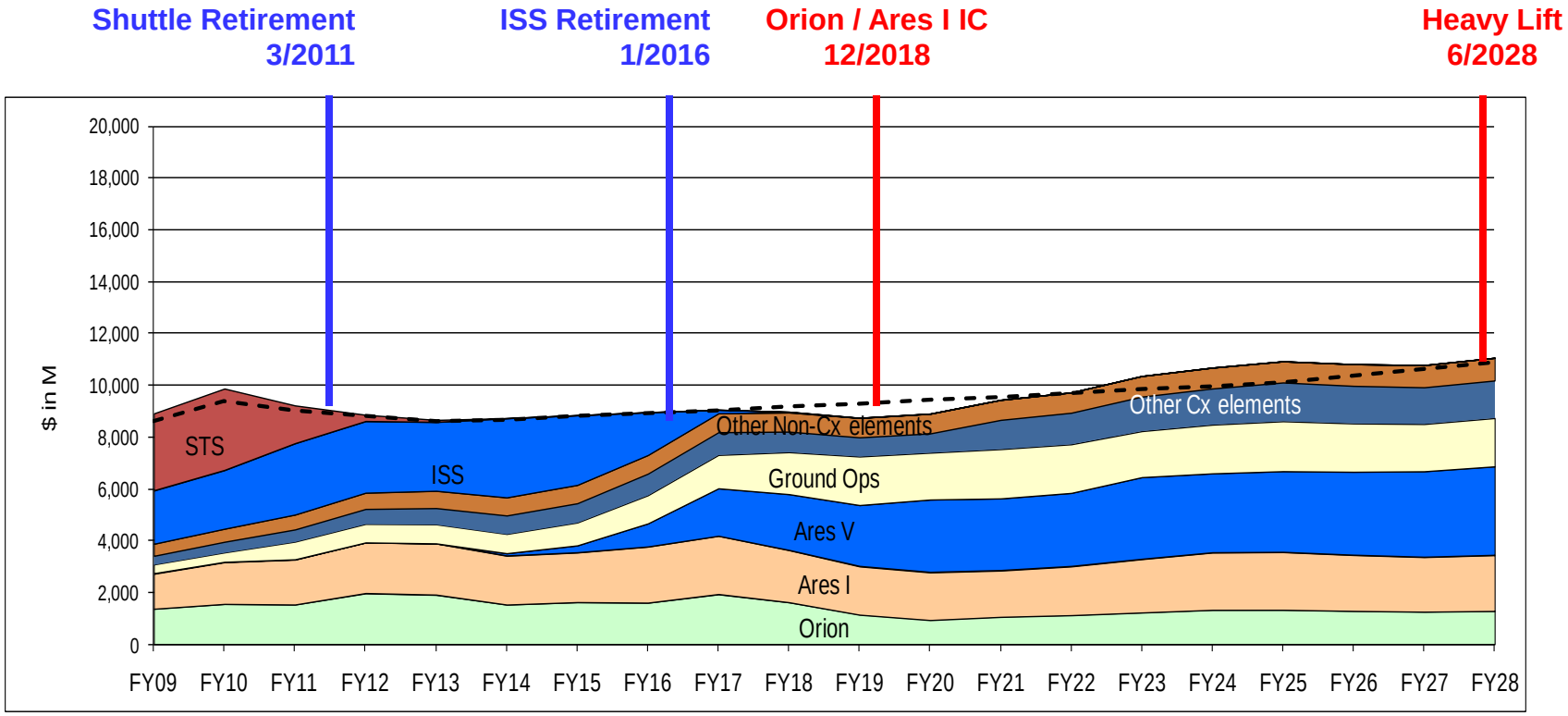
Simulation Results (65% Likelihood)	
Date: Crew to LEO	June 2016
Date: Human Lunar Return	Oct 2021
Cost RY$B: FY10 thru 2020	$ 149
Cost RY$B: FY10 thru 2030	$ 307

Program of Record - Derived Baseline

- Program of Record fit to FY10 President's budget
- Shuttle fly-out in March, 2011
- ISS retirement in early 2016
- Commercial/International Engagement as in program



Program of Record - Derived Baseline – FY10 Budget

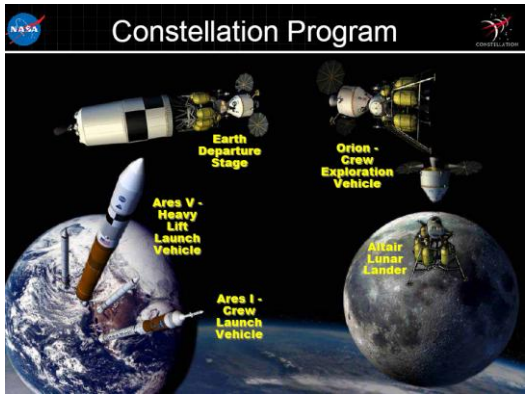


Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2016
Extra Soyuz flights for crew to ISS

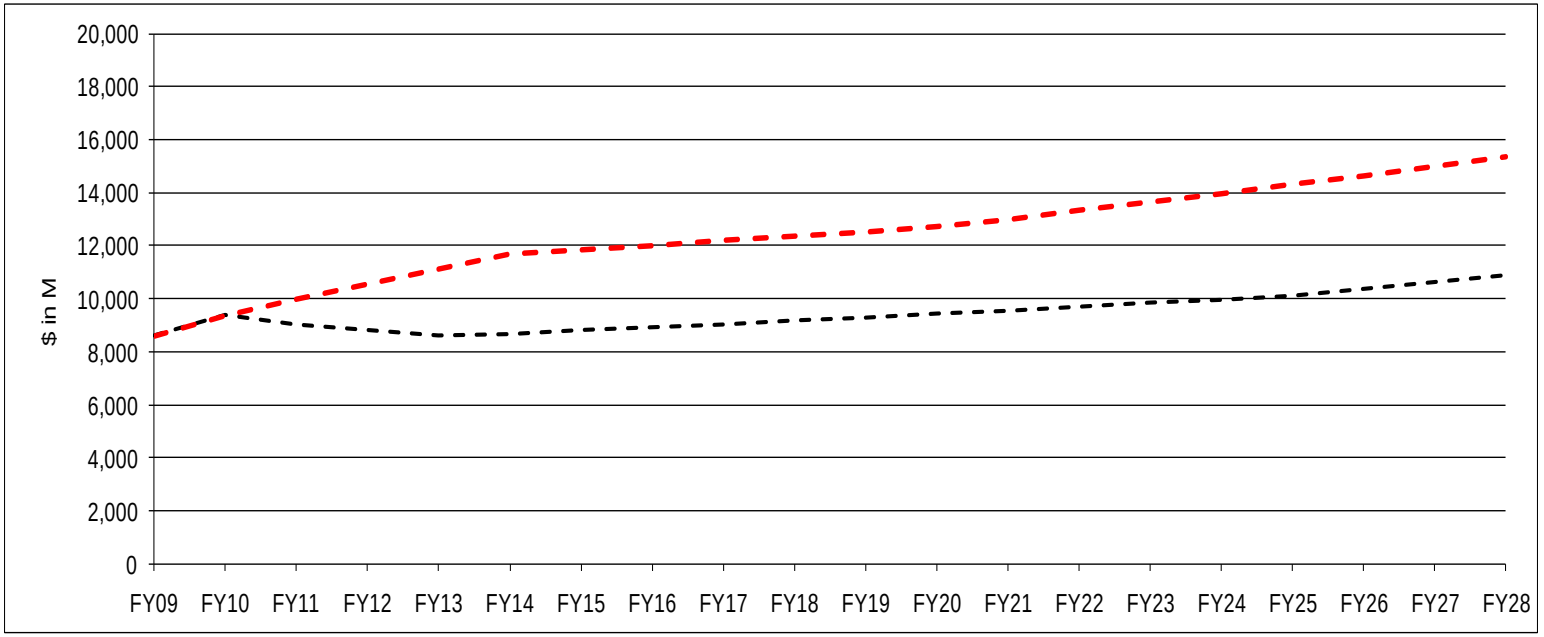
Simulation Results (65% Likelihood)	
Date: Orion / Ares I IC	Dec 2018
Date: Heavy Launch IC	Jun 2028
Cost RY$B: FY10 thru 2020	$99
Cost RY$B: FY10 thru 2030	$205

Program of Record- “Less Constrained”

- “Less constrained” budget (next chart)
- Shuttle fly-out in March, 2011
- ISS retirement in early 2016
- Commercial/International Engagement as in program

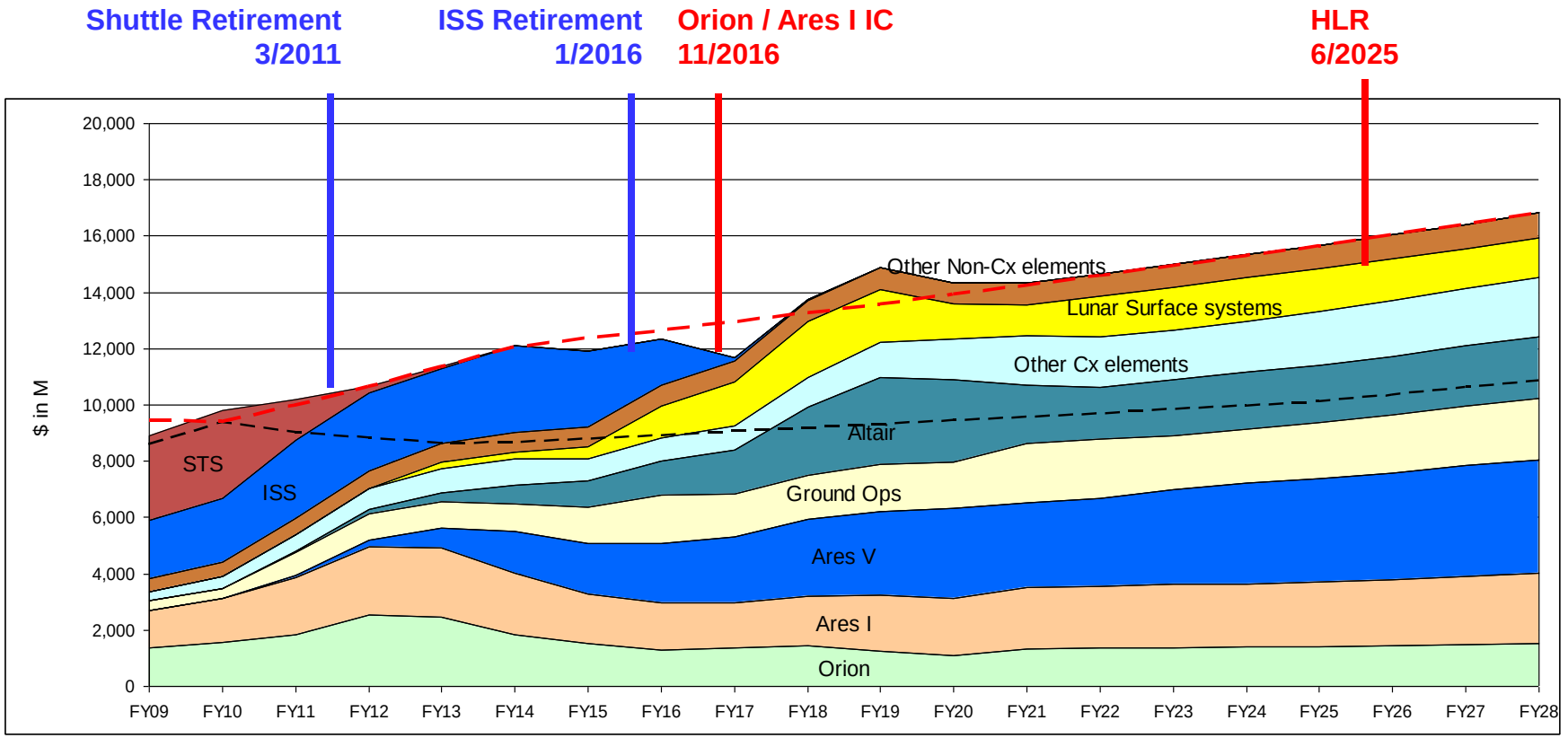


FY 10 and “Less Constrained” Budgets



	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY10-FY20	FY10-FY25
Avalible HSF budget	8,599	9,387	9,024	8,817	8,617	8,681	8,802	8,925	9,050	9,177	9,305	9,436	9,568	9,702	9,838	9,975	10,115	10,358	10,606	10,861	99,220	148,418
Proposed HSF budget	8,599	9,387	9,961	10,534	11,107	11,681	11,844	12,010	12,178	12,348	12,521	12,697	13,001	13,313	13,633	13,960	14,295	14,638	14,990	15,349	126,268	194,471

Program of Record Derived Baseline – Less Constrained



Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2016
Extra Soyuz flights for crew to ISS

Simulation Results (65% Likelihood)	
Date: Crew to LEO	Nov 2016
Date: Human Lunar Return	Jun 2025
Cost RY$B: FY10 thru 2020	$ 129
Cost RY$B: FY10 thru 2030	$ 275

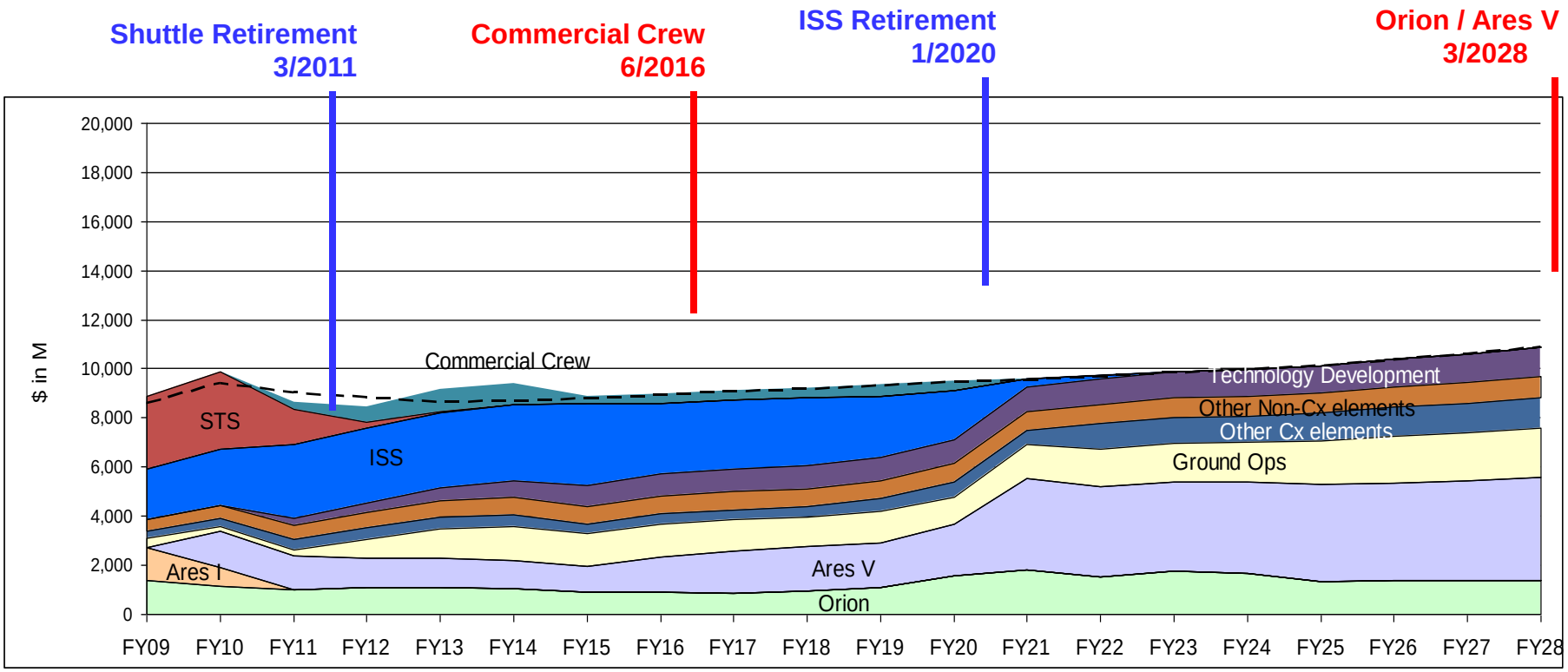
New Scenarios

- For all that follow:
  - Technology line added
  - Additional COTS (cargo) $200 M
  - If Commercial crew to LEO, added $2.5 B total, FY11-14
- Next set of scenarios attempted to fit FY10 (constrained) budget
  - ISS-focused
  - “Dash” out of LEO

ISS Focused: Commercial Crew to LEO

- Focus in the next decade on ISS
- Attempt to fit FY10 budget
- Shuttle fly-out in March, 2011
- ISS extension to 2020
- Commercial/International Engagement

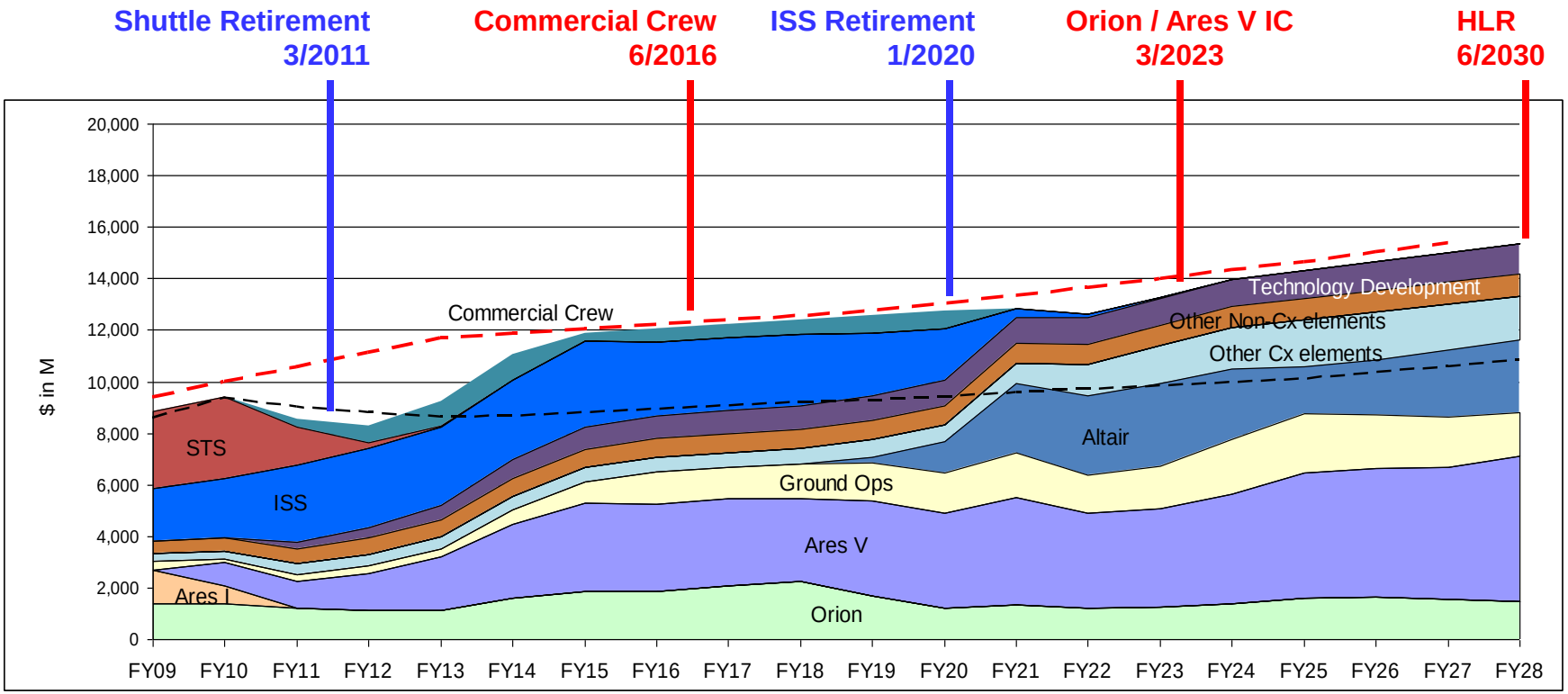
ISS Focused – Commercial Crew for LEO – FY10



Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2020
Extra Soyuz flights for crew to ISS
Technology Development Program

Simulation Results (65% Likelihood)	
Date: Orion / Ares V IC	March 2028
Cost RY$B: FY10 thru 2020	$ 101
Cost RY$B: FY10 thru 2030	$ 204

ISS Focused – Commercial Crew for LEO – Less Constrained



Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2020
Extra Soyuz flights for crew to ISS
Technology Development Program

Simulation Results (65% Likelihood)	
Date: Orion / Ares V IC	March 2023
Date: Human Lunar Return	June 2030
Cost RY$B: FY10 thru 2020	$ 121
Cost RY$B: FY10 thru 2030	$ 264

Dash out of LEO

- Get to non-lunar beyond LEO target as soon as possible

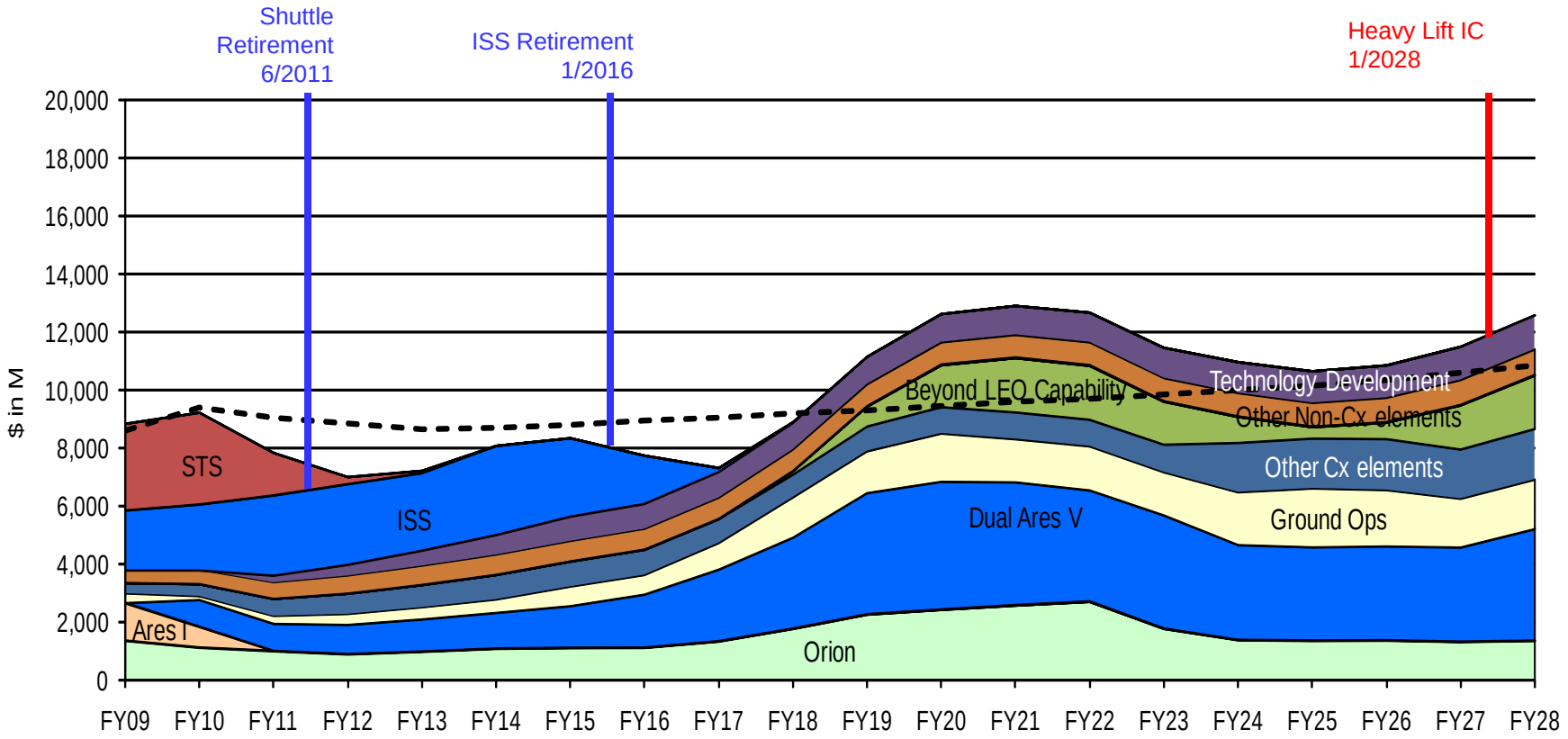
  (using deep space option)

- Shuttle fly-out in March, 2011

- ISS De-Orbit in early 2016

- Lunar surface program moved to future

Dash out of LEO



Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2016
COTS Supplemental ($200M)
IP Crew (e.g. extra Soyuz flights)

Simulation Results (65% Likelihood)	
Date: Heavy Lift IC	**Jan 2028**
Cost RY$B: FY10 thru 2020	$95
Cost RY$B: FY10 thru 2030	$216

Orion, Heavy Lift LV Initial Capability for Dash out of LEO realized by January 2028; NEO mission, Lunar Lander, Venus Flyby content is lost

FY10 Budget Constrained Cases

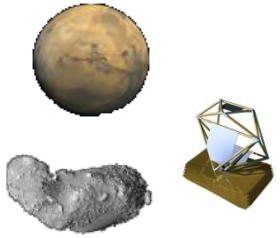
- Current budget guidance extremely limiting. So far, no scenarios that include exploration that are viable
- ISS-focused – Ares 1 arrives too late; commercial crew to LEO can support ISS, but Ares V arrives in 2028 with no lunar surface systems started.
- “Dash” out of LEO…isn’t. (Heavy lift capability in 2028, no lunar surface systems).
- (still looking)

Next Set – “Less Constrained”

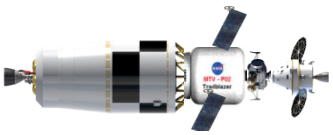
- Initially ran each as unconstrained. All significantly outside budget guidance
- Adjusted to fit “Less Constrained” budget
- Scenarios:
  - “Deep Space” (3 different HLV options)
  - “Lunar Global” (2 HLV options)
  - “Use Shuttle Systems” (Close the gap)
  - “Mars First”

Deep Space- Dual Ares V (lite)

- Shuttle fly-out in March, 2011
- ISS extension to 2020
- Program of Record Ares I/Ares V vehicles replaced with 2 Ares V lite vehicles
- Robust Technology Development
- Commercial Crew to LEO
- Lagrange points, NEOs, fly-bys
- Defer Lunar Lander and surface systems (Commercial/gov't)

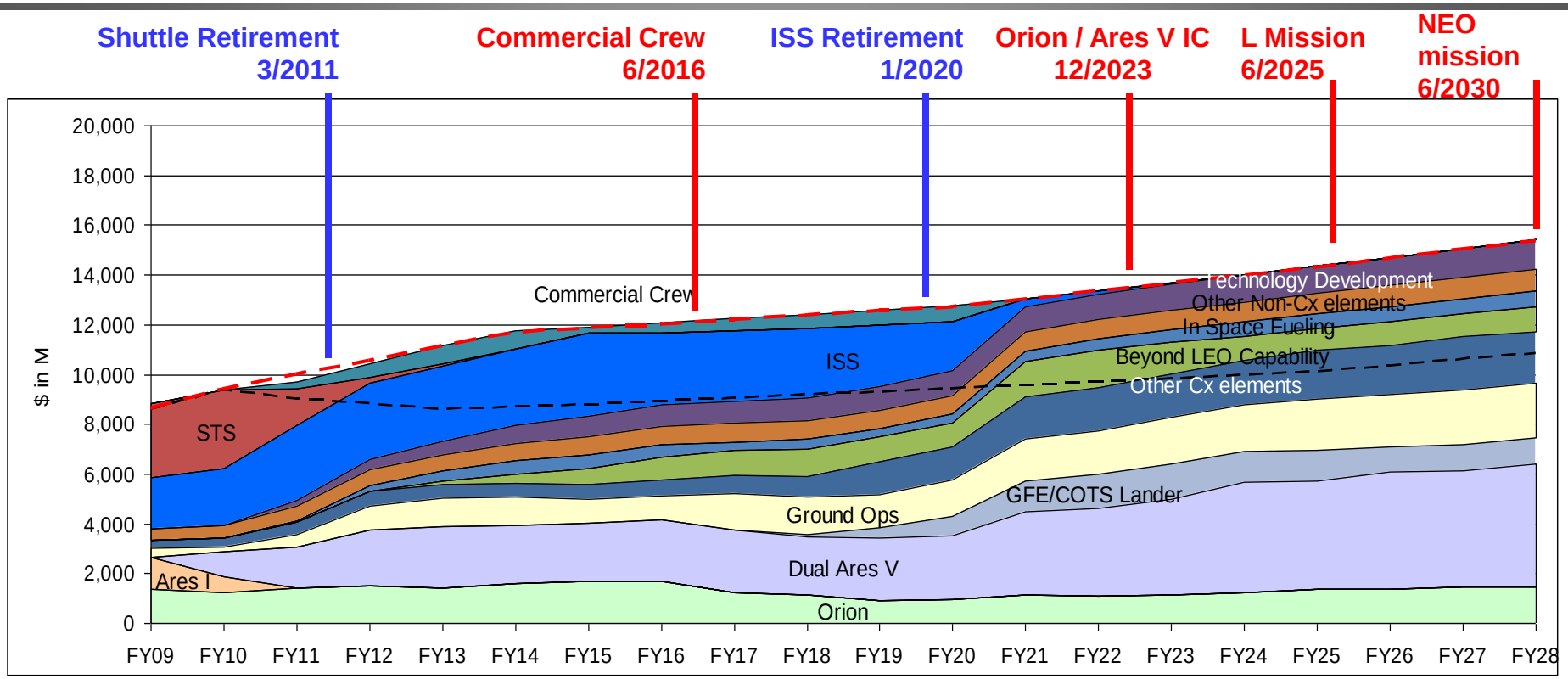


Flybys, NEOs, Lagrange Points



In-Space Transit

Deep Space (Dual Ares V) - Less Constrained



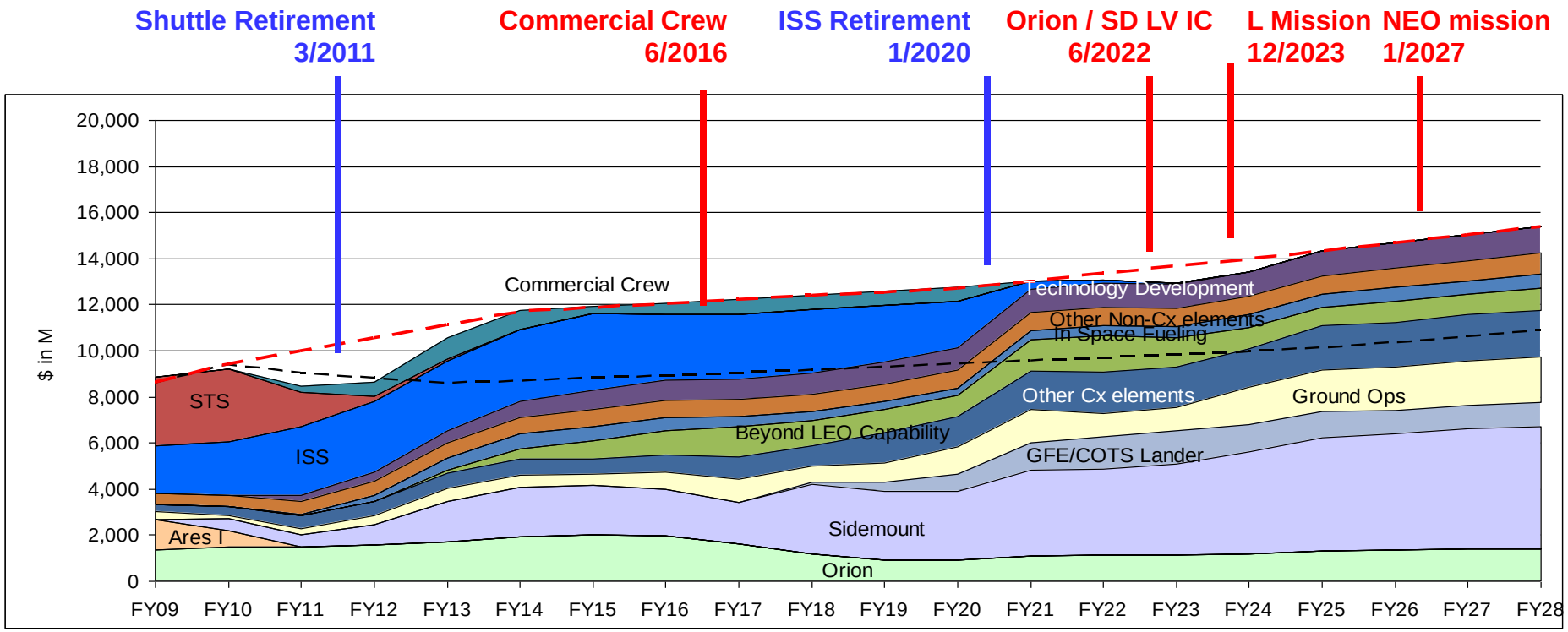
Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2020
Extra Soyuz flights for crew to ISS
Technology Development Program

Simulation Results (65% Likelihood)	
Date: Orion / Ares V (Dual) IC	**Dec 2023**
Date: L Mission	**June 2025**
Date: NEO mission	**June 2030**
Date: Mars Flyby	**June 2034**
Date: HLR	**June 2035**
Cost RY$B: FY10 thru 2020	**$ 126**
Cost RY$B: FY10 thru 2030	**$ 272**

Deep Space – Directly Shuttle-Derived

- Shuttle fly-out in March, 2011
- ISS extension to 2020
- Directly Shuttle-Derived (100 MT) for cargo
- Robust Technology Development
- Commercial Crew to LEO
- Lagrange points, NEOs, fly-bys
- Defer Lunar Lander and surface systems

Deep Space – Shuttle-Derived – Less Constrained



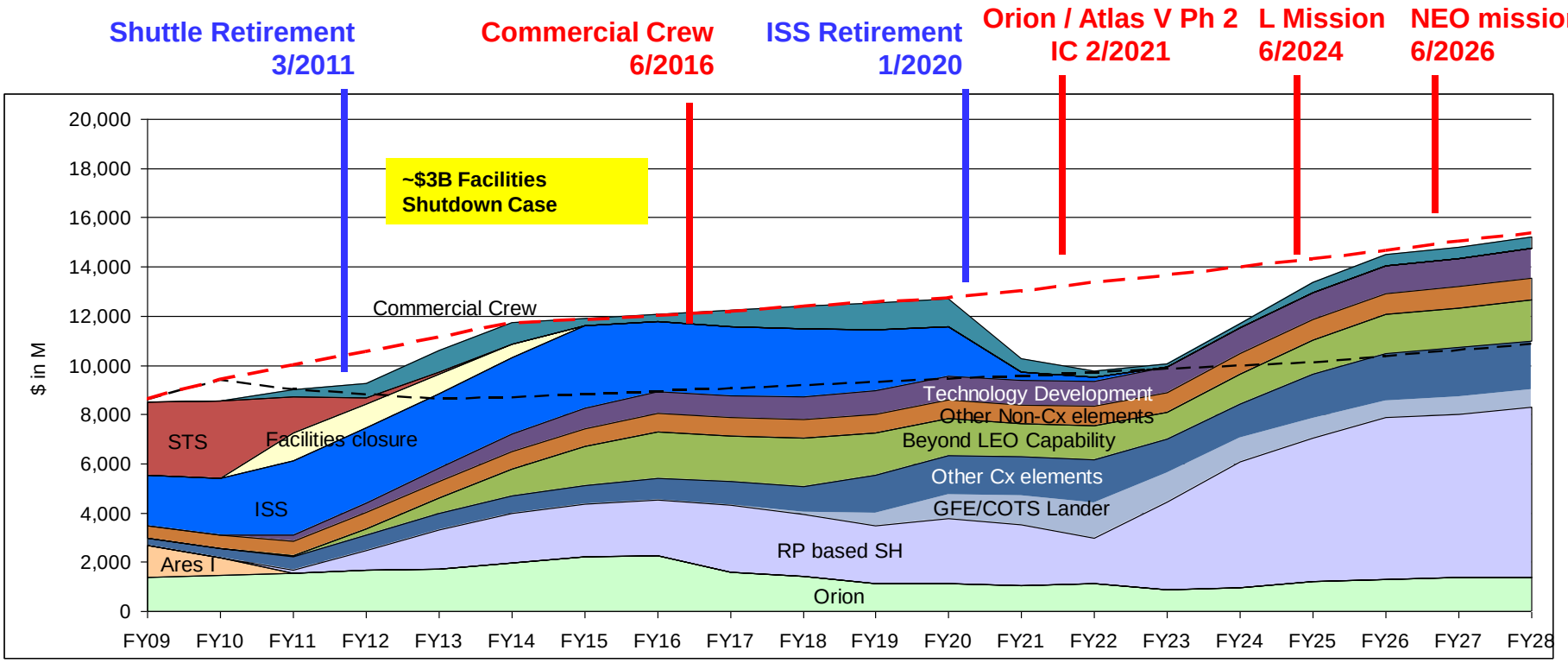
Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2020
Extra Soyuz flights for crew to ISS
Technology Development Program

Simulation Results (65% Likelihood)	
Date: Orion / Shuttle-Derived (cargo)	**Jun 2022**
Date: L Mission	**Dec 2023**
Date: NEO mission	**Jan 2027**
Date: Mars Flyby	**Jan 2029**
Date: HLR	**Jan 2030**
Cost RY$B: FY10 thru 2020	**$ 123**
Cost RY$B: FY10 thru 2030	**$ 266**

Deep Space – Commercial Hydrocarbon Booster

- Shuttle fly-out in March, 2011
- ISS extension to 2020
- Heavy lift: 75 MT commercial vehicles
- Robust Technology Development
- Commercial Crew to LEO
- Lagrange points, NEOs, fly-bys
- Defer Lunar Lander and surface systems

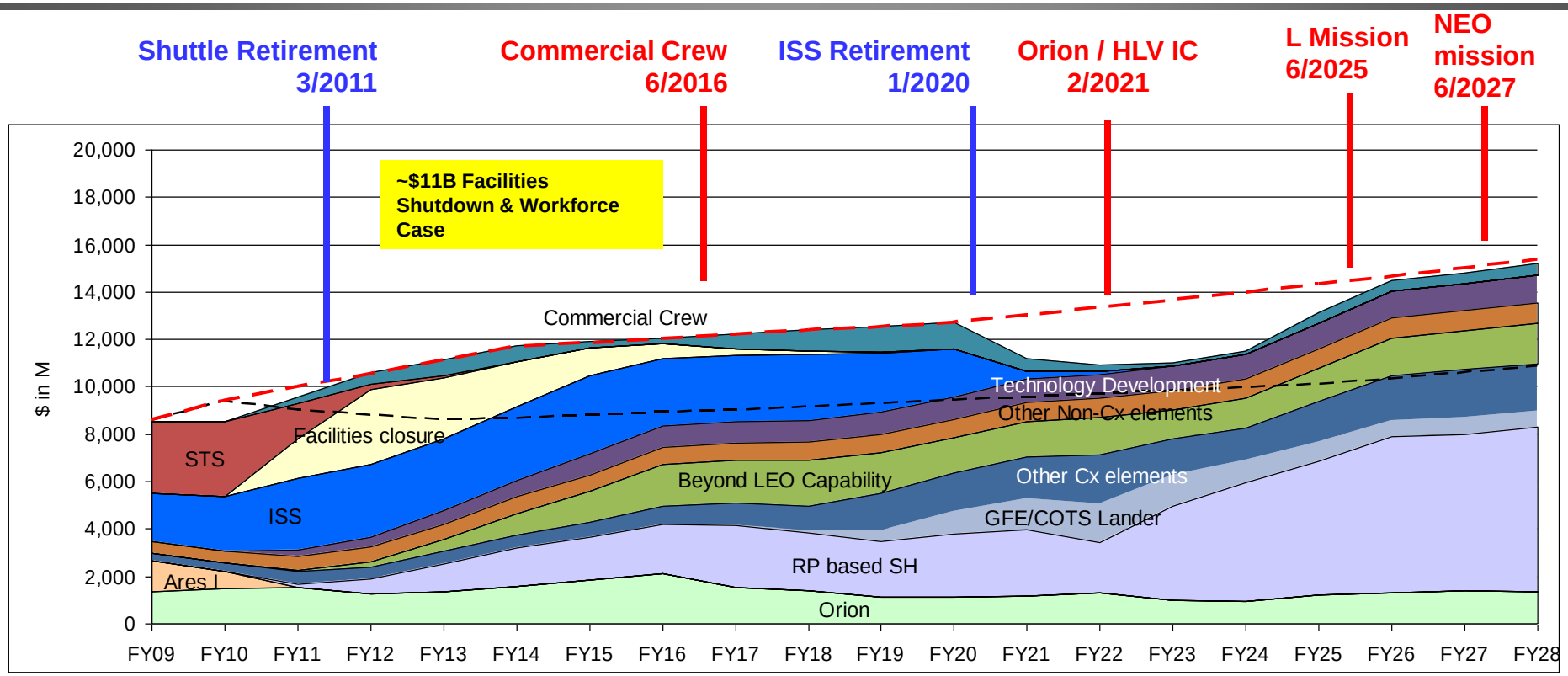
Deep Space (Commercial Booster) – Less Constrained



Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2020
Extra Soyuz flights for crew to ISS
Technology Development Program

Simulation Results (65% Likelihood)	
Date: Orion / HLV IC	Feb 2021
Date: L Mission	June 2024
Date: NEO mission	June 2026
Date: Mars Flyby	June 2028
Date: HLR	June 2029
Cost RY$B: FY10 thru 2020	$ 123
Cost RY$B: FY10 thru 2030	$ 256

Deep Space (Commercial booster) – Less Constrained



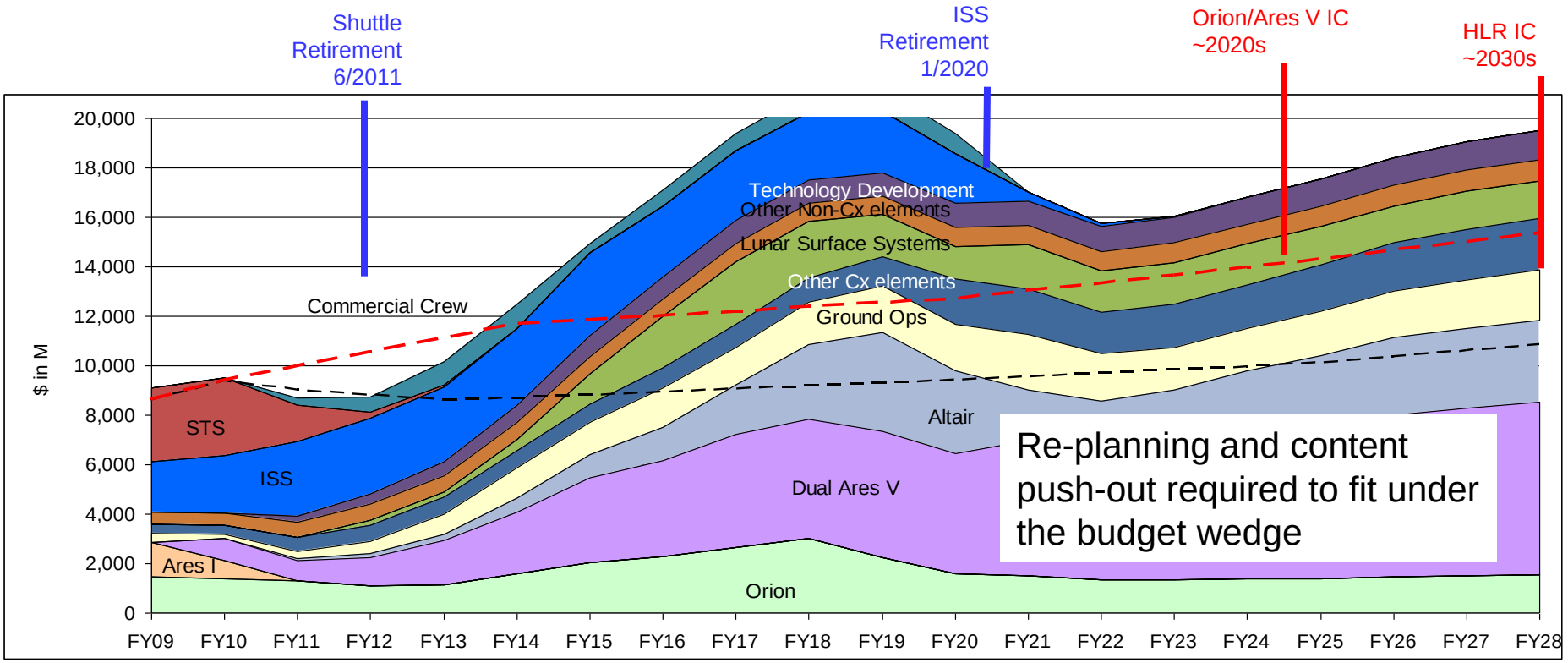
Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2020
Extra Soyuz flights for crew to ISS
Technology Development Program

Simulation Results (65% Likelihood)	
Date: Orion / commercial HLV IC	Feb 2021
Date: L Mission	June 2025
Date: NEO mission	June 2027
Date: Mars Flyby	June 2029
Date: HLR	June 2030
Cost RY$B: FY10 thru 2020	$ 123
Cost RY$B: FY10 thru 2030	$ 266

Lunar Global - Ares V

- Shuttle fly-out in March, 2011
- ISS extension to 2020
- Commercial Crew development
- Ares V dual heavy lift
- Robust Technology Development
- Changes surface exploration approach

Lunar Global Ares Less Constrained



Budget Assumptions
Shuttle Extension to 2011
ISS Retirement in 2020
Extra Soyuz flights to ISS
Commercial Crew
Refueling Capability

Re-planning Required (Rough estimate dates)	
Date: Orion / Ares V IC	**Mid 20s**
Date: Human Lunar Return	**Late 20s**
Date: Outpost	**Early 30s**

Orion and Heavy Lift (Dual Atlas V) realized in mid-20s, HLR realized in late 20s; Outpost in 2030s (approximate dates only)

Use Shuttle Systems (Close the Gap)

- **Shuttle extension, at minimum rate (1-2 flts/yr), to 2015**
- **ISS extension to 2020**
- **Commercial crew to LEO**
- **Directly Shuttle-Derived Heavy Lift (Cargo only)**
- **Technology program**
- **Lunar Sortie/Outpost**

Mars Direct

- Considerably higher cost than other scenarios
- Cost analysis of other scenarios done first
  - After those results, it was clear that this wouldn't fit-- even within "Less Constrained" budget.
- Likely approach under these budgets:

  focus on robust technology development to improve capabilities for eventual Mars Direct scenario

Summary

Summary

- Important components:
  - Technology program
  - Commercial crew capability to LEO
- Exploration doesn't appear viable under the FY10 budget and run-out
  - Even Dash out of LEO doesn't achieve anything
  - Still looking for "existence proof"
- Some things are more expensive than others
  - Deep Space is most cost effective of exploration scenarios, with earlier return
  - Some Heavy lift options other than program of record appear more cost effective (though less lift capability)